Total Army Personnel Life Cycle Model: Development of a General Algebraic Modeling System Formulation

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14. ABSTRACT *(Maximum 200 words)*:

This paper describes the Total Army Personnel Life Cycle Model (TAPLIM) policy analysis model. A description of TAPLIM's features and solution methodology is presented. The paper also describes the conversion of TAPLIM into a formulation suitable to run in the General Algebraic Modeling System (GAMS) software. The result is an easy-to-use, maintain, and update model. This version of TAPLIM more efficiently accommodates the analysis of multiple personnel policies, decreases running time, and produces output that is suitable for import into a spreadsheet or immediate examination. Examples are presented to illustrate capabilities of the GAMS version of TAPLIM.

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Total Army Personnel Life Cycle Model: Development of a General Algebraic Modeling System

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Selection and Assignment Research Unit
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The Selection and Assignment Research Unit of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) performs research on manpower and personnel issues of particular interest to the U.S. Army. This study describes the conversion and application of a personnel policy analysis model, the Total Army Life Cycle Model (TAPLIM). This model, which was developed by Colonel (retired) Anthony Durso and Major Scott Donahue in the Army's Office of the Deputy Chief of Staff of Personnel, can be used to analyze the long-term consequences of changes in enlisted personnel and organizational policies over time. This project converts TAPLIM into an easy-to-use, maintain, and update General Algebraic Modeling System (GAMS) formulation. This formulation makes the model more efficient, maintainable, flexible, and transportable.

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TOTAL ARMY PERSONNEL LIFE CYCLE MODEL: DEVELOPMENT OF A GENERAL
ALGEBRAIC MODELING SYSTEM FORMULATION

EXECUTIVE SUMMARY

Research Requirement:

The Total Army Personnel Life Cycle Model (TAPLIM) was designed
and implemented by Colonel (Retired) Anthony Durso and Major Scott F.
Donahue within the Office of the Deputy Chief of Staff of Personnel
(ODCSPER) to study the impact of personnel management policies on the
U.S. Army's enlisted force. TAPLIM is capable of analyzing the long-
term effects of a variety of enlisted personnel policies, including the
impact of changing retention control points, promotion rates, terms of
enlistments, modifying tour lengths. Moreover, model solutions provide
readiness implications of policies. TAPLIM, as originally formulated,
is difficult to modify and update. By making it easier to maintain and
use, its potential as a valuable tool can be enhanced.

Procedure:

TAPLIM was originally formulated for use under the Linear,
Interactive, Discrete Optimizer (LINDO) optimization software. In this
study TAPLIM is reformulated in an algebraic format and rewritten to run
under the General Algebraic Modeling System (GAMS) modeling software.
This involves grouping the constraints to be rewritten in algebraic
expressions, compiling the coefficients and right hand sides into tables
separate from the expressions, and organizing the resulting output data.
The GAMS model is verified by comparing its output to an existing
solution obtained from the LINDO version.

Findings:

Several benefits are achieved from the conversion of TAPLIM. The
GAMS version of the TAPLIM model runs considerably faster than the LINDO
version. Modification of model parameters, both coefficients and right
hand side values, is more convenient since parameter values are in
tables with appropriate indices. Extending the projection horizon of
the model is also simplified because of the indexing capabilities of
GAMS. The GAMS version of TAPLIM produces two output files; one file
presents the solutions in tables that can be immediately examined, and
the other is in a format for direct import by a spreadsheet package.

Utilization of Findings:

Using the GAMS version of TAPLIM, efficient and expeditious
investigations of the long-term effects of personnel policies are
possible. And, with the GAMS version, TAPLIM can now be run on PC's,
mini and mainframe platforms.

TOTAL ARMY PERSONNEL LIFE CYCLE MODEL: DEVELOPMENT OF A GENERAL
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Objectives

The successful implementation and establishment of a policy
analysis model depend, to a great extent, on how easy it is to use and
maintain. Models that are difficult to use and maintain do not survive;
they fall into disuse. The objective of this project is to help in
establishing the Total Army Personnel Life Cycle Model (TAPLIM) as a
policy analysis tool in the Army's Office of the Deputy Chief of Staff
of Personnel (ODCSPER). This paper documents the conversion and
verification of TAPLIM into the easier-to-use and maintain General
Algebraic Modeling System (GAMS) formulation. An illustration of the
types of policies TAPLIM is capable of analyzing is also presented.
This demonstrates the relative ease of application and modification
inherent in the GAMS formulation.

History of TAPLIM

Background

When the Army initiated its restructuring and downsizing in the
early 1990's, ODCSPER recognized the need for a policy analysis model
that could examine the long term consequences of proposed personnel
strategies. The result is TAPLIM, a multi-period, multiobjective linear
programming manpower model.[1] TAPLIM is an effective tool to analyze the
long term effects of personnel policy changes on enlisted personnel
inventory. It has been used to analyze various policies put forth in
support of the National Defense Authorization Act (1992), and as a
prototype for the development of other models, such as the Officer
Inventory Projection Model, the Casualty Replacement Model for Operation
Desert Storm, and the Army Nurse Recruiting Model. In 1994 TAPLIM was a
finalist for the Franz Edelman award for Achievement in Management
Science Practice, sponsored by The Institute of Management Sciences
(TIMS) and the College on the Practice of Management Science (CPMS). An
article describing TAPLIM was published in the Edelman Award edition of
the journal Interfaces (January-February, 1995).

The TAPLIM Model

TAPLIM is a suite of models: the basic inventory model and three
extensions. This paper discusses the basic model and two of the
extensions, the term of service (TOS) and permanent change of station
(PCS) extension.

Basic Inventory Formulation

The basic TAPLIM model is a generalized network flow model with
side constraints tracking soldier movement over time by grade and years

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[1] TAPLIM was created by Colonel (retired) Anthony Durso, D.Sc., and
Major Scott Donahue, M.Sc., Directorate of Military Personnel
Management, ODCSPER

of service (YOS). The flow balance equations model the career progression of enlisted soldiers in the Army. The alternatives available to an enlisted soldier are to continue in the same grade, be promoted to the next higher grade, or separate from the Army. The typical conservation of flow equation has the following form:

$$E_{j,k,t} + P_{j+1,k,t} + S_{j,k,t} = C_{j,k-1,t-1}[P_{j,k-1,t-1} + E_{j,k-1,t-1}],$$

$E_{j,k,t}$ = Soldiers in grade j, with k YOS, in period t;

$P_{j,k,t}$ = Soldiers promoted to grade j, with k YOS, in period t;

$S_{j,k,t}$ = Soldiers involuntarily separated from the Army in grade j, with k YOS, in period t;

$C_{j,k,t}$ = Continuation rate of soldiers in grade j, with k YOS that are expected to remain in the Army

This equation represents the expected number of enlisted soldiers in each grade/year of service combination that will remain in the Army from one fiscal year to the next[2]. The continuation rates are average rates estimated from historical data. These continuation rates are a critical component of the network equations because they determine how accurately the model's aging process simulates actual soldier behavior.

The possible career paths taken are controlled by side constraint equations. These equations represent policies, regulations, and goals that insure that the Army's personnel requirements are met each time period. The side constraints establish promotion floors for each grade and period and promotion ceilings for sergeant major's (E9), distribute promotions for each grade across years of services in each period, establish minimum and maximum annual levels of accessions, set maximum combined manning levels for the ranks of master sergeant (E8) and sergeant major in each period, set end strengths for each period, and align the enlisted inventory to force structure for each grade and period. These constraints reflect the Army's organizational goals and provide fair and equitable career progression for soldiers.

The primary goal of the Army's personnel system is to fill authorized enlisted jobs with qualified soldiers, making the Army as ready as possible. An important aspect of the side constraints is the ability to measure the effect of personnel policies on overall readiness. In each side constraint that assigns inventory to force structure vacancies (i.e., faces to spaces), variables are introduced to measure the difference between the number of vacancies and the number of qualified personnel actually available -- overdeviation and

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[2] See Anthony Durso and Major Scott Donahue, <u>An Analytical Approach to Reshaping the United States Army</u>, Interfaces, pg 113.

underdeviation. The summation of these variables across grades and years is the operating strength deviation (OSD). Ideally, the OSD would be zero, indicating an exact match of personnel to jobs. However, given limited resources and constraints representing other personnel requirements, the best one can expect is to minimize the OSD in the objective function.

Overall, TAPLIM has four objectives to optimize. The objectives are to minimize OSD, to minimize involuntary separations and accessions, and to maximize promotions. Each objective is weighted. Because the primary goal is to meet end strength, minimizing OSD is given the largest priority weight. The model penalizes for both deviating below and above end strength targets (underdeviation and overdeviation, respectively). The latter three objectives are equally weighted.

Term of Service Extension

Previous research has found that there are significant differences in the continuation behavior of individuals enlisting for different terms of service (TOS)[3]. TAPLIM's developer extended the basic model by adding a term of service dimension to take into account these differences, and more accurately reflect the movement of enlisted personnel. This dimension differentiates two, three, four, five, and six year contract soldiers.

The TOS equations represent the flow of enlisted personnel by their term of service contract during the first six years of their military careers. The variables in these equations are indexed by TOS option, years of service, and time. The equations simulate the progression of soldiers through their first six years in the Army. After six years of service, the TOS variables are collapsed into a single variable. The greater detail in the flow equations provides additional insight into the effect of accession policies on Army force structure and manning.

Permanent Change of Station Extension

Over the next few years the proportion of the Army stationed outside the continental United States (OCONUS) will decline substantially. Before the recent restructuring there was approximately a 55-45 split between continental U.S. vs. outside the continental U.S. (CONUS-OCONUS). In briefings in early 1994 the Enlisted Personnel Management Directorate of the Total Army Personnel Command (PERCOM) assumes that this split will go to 70-30 by mid-1998. The permanent change of station (PCS) extension was introduced to investigate the consequences of this tremendous change. The PCS extension provides the capability to analyze the movements of personnel not only by career progression, but also by geographic location. This was accomplished with additional flow and side constraints embedded in the basic TAPLIM model. The variables in the PCS extension are subscripted by grade, the geographic area departed, the area entered, and time. This extension allows for the distribution of personnel in one geographic location

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[3] Smith, Sylvester, and Villa, 1991

during time period t-1 to other allowable geographic locations in time period t. Because there are movements from nine locations to a maximum of ten others for each grade and fiscal year, the number of equations increases significantly for the PCS extension of TAPLIM.

A significant addition of the PCS extension is its method of measuring deviation. The Operating Strength Deviation equations were reformulated not only to measure OSD by grade and time period, but also by *geographic area*. This gives OSD, the main component of the objective function, enhanced detail of areas where manning difficulties may exist.

In addition to the geographic locations, the PCS extension also takes the "in training, in transient, in holding, in school" (TTHS) account into consideration. Soldiers in TTHS do not contribute to operating strength but must be accounted for in the personnel inventory. The PCS extension also distributes voluntary and involuntary losses across geographic area and grade. Therefore, all enlisted personnel are accounted for and are either considered in a geographic area, in TTHS, or a loss.

The LINDO Version of TAPLIM

TAPLIM's formulation was originally implemented in LINDO linear programming software. The LINDO formulation explicitly represents each equation of the model. Substantial effort is required to develop a model in this fashion because the user has to input every equation. An eight time period version of TAPLIM with the PCS extension requires explicitly representing approximately fifty-five hundred equations with a total of fifty thousand variables. Formulating TAPLIM, or any large model, in this fashion is a time-consuming process. Modification of equations or parameters is also difficult because an analyst must locate all the necessary coefficients and right hand sides and change them line by line. In addition, the LINDO code takes 20 minutes to run on a Sun SPARC station. If multiple runs or models with more time periods are undertaken, a significant amount of time is spent modifying the linear program and running it.

Another limitation of LINDO is its limited output format. The results are output as a single list of variables and their values. This output must then be imported into a spreadsheet or other software package to be converted into a table or other format that is useful. Manipulating the data takes a large amount of time, even after writing a macro to automate the process.

Approach to Conversion

The GAMS Linear Programming Software

The General Algebraic Modeling System (GAMS) is an algebraic modeling language that allows the user to input a linear program in its algebraic formulation. Algebraic modeling is a convenient method of expressing a linear program; using symbolic notation, a model can be easily stated and understood by other users. An algebraic modeling language can interpret these algebraic expressions, allowing the

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programmer to input a linear program in a more concise fashion. GAMS then generates the required code based on the algebraic formulation.

The advantages of the algebraic method of inputting a linear program are substantial:

- The size of the algebraic formulation is not related to the size of the linear programming model. If an analyst wanted to add more years to the model, one simply increases the indices and adds the necessary coefficients to the tables. GAMS will generate the necessary equations.

- GAMS is especially useful for large scale linear programming models. Given that most models display a redundant pattern of equations, the analyst can take advantage of the redundancy to significantly decrease the size of the written algebraic code.

- Numerical data is stored outside the algebraic formulation. Coefficients and right hand sides are structured as tables, parameter lists, or as constants. Updating or modifying data is then simply modifying one part of the program and not hunting down every equation to change the numerical data. The data can also be stored in external files, keeping access to the algebraic model minimal and ensuring the integrity of the model.

- GAMS runs with various popular optimizers, such as MINOS5, ZOOM and IBM's Optimization Subroutine Library (OSL). These optimizers are relatively quick and can solve linear, nonlinear and integer programming models. OSL, for example, is a very efficient solver with many options such as scaling, presolving and crashing. OSL also provides primal, dual and interior point solution algorithms.

There are instances when the GAMS algebraic code can become encumbered. This occurs particularly when accommodating exceptions for either equations or variables within the GAMS code. For example, if in the TAPLIM model a minimum level of promotions is required in every grade and period except the grade of E5 in FY93, then this must be reflected by the GAMS code. However, GAMS does have a feature to exclude either variables or entire equations for given situations. Nonetheless, if a model requires significant use of this feature then the clear and concise nature of the GAMS code is reduced.

The Conversion Process

The conversion of TAPLIM into a GAMS formulation involves two stages: translation of the LINDO formulation into GAMS expressions and verification of the resulting code. The conversion of the LINDO equations into a GAMS algebraic formulation consisted of formulation of algebraic expressions and the organization of coefficients and right hand sides into tables. The first step was to identify equations with

similar structure in the LINDO version of TAPLIM. Acquiring an understanding of the Army's enlisted personnel policies, procedures and its organizational structure helped in identifying equations that were accomplishing the same objectives. Equations that maintained the same structure by grade, YOS or time are represented by a single algebraic expression that is written into the GAMS formulation. However, there are grade specific policies and, in some instances, YOS and time specific policies. These equations are divided further by their distinctions so that one GAMS expression is written for each group.

The final step of the conversion is the creation of data tables. Coefficients and right hand side values were part of each equation in the LINDO model. GAMS keeps this information separate from the algebraic formulation. This part of the conversion involved retrieving and typing data in tables indexed by two or more dimensions. If these values have to be modified, an analyst simply modifies the tables, versus having to edit every equation in the model.

The GAMS code creates two TAPLIM solution files with different formats. The solution listing in the first file is printed in a table format. An analyst could scan across the page to observe the change in accessions by time period, or the level of personnel by grade and geographic area. The second file contains a single line listing of the variables in comma-delimited format for import into a spreadsheet.

Verification of GAMS Model

Verifying the GAMS algebraic code is the second phase of the TAPLIM conversion into GAMS. This study employs three methods of verification: the matching of the LINDO and GAMS objective values for identical runs, the matching of individual variable values, and comparison of the equations GAMS generates from the algebraic formulation to the LINDO equations.

The LINDO and GAMS objective functions match to the third decimal place. An exact match is not expected because of the differences in the software's arithmetic precision. Since the scale of the model is in thousands of soldiers, an objective value of 108.578437 signifies 108,578 soldiers. This supports the argument that the LINDO and GAMS formulations match down to individual soldiers.

The comparison of individual variable solutions showed discrepancies between the two TAPLIM versions. While the variables in the basic inventory and the TOS extension matched exactly, the PCS portion differed substantially in nearly every single variable. The variables in the PCS extension track personnel by grade, their departing location, the entering location, and time period. Because these variables are loosely bounded and the constraints are not tight, multiple alternative optimal solutions exist. This implies it is possible for the LINDO and GAMS formulations to produce objective values agreeing to three decimal places, and yet have differing solution values in the PCS extension portion of TAPLIM.

The most thorough and precise method of verification was comparing each equation generated by the GAMS algebraic formulation to each equation in the LINDO model. This ensured GAMS was generating every equation present in the LINDO model, and also not generating extraneous equations. This procedure was performed twice to ensure all errors were corrected.

Hardware and Software Requirements

GAMS is available to run on any mainframe and on 386 and higher personal computers. GAMS runs with limited precision so that formulations will produce the same result when it is run on different platforms. Therefore, the output produced on one machine should be reproducible on another.

GAMS requires large amounts of hard disk space to write temporary and output files. It is also beneficial to have a large amount of memory for GAMS to work with due to the matrix manipulations involved. While GAMS can run with 640k of RAM on a personal computer, the TAPLIM algebraic model requires at least four megs of RAM. Depending on the solution algorithm (simplex or interior point), finding an optimal solution to the TAPLIM model takes GAMS approximately between 45 seconds to seven minutes on a VAX VMS for an eight period model. Although comparison of times will vary by computer systems, there appears to be a large savings in time compared to the LINDO model, which ran for approximately 20 minutes on a Sun SPARC Station.

Illustration of Policy Analysis Capability

To demonstrate the capabilities and versatility of the GAMS formulation of TAPLIM this paper presents an illustrative policy analysis. The policy scenarios examined are for illustrative purposes only. They are not advocated or proposed policies but serve to show some of the applications of TAPLIM.

The current downsizing and restructuring of the U.S. Army will result in significant reductions in overseas requirements. A smaller CONUS-based force is the Army's immediate future. In this new environment, the number of rotational moves -- the permanent changes of station between the continental U.S. and overseas locations-- is significantly reduced. These moves have been "bill payers" for promotion and professional development. Promotion opportunities have been facilitated by the requirement for rotational moves (to/from overseas). Similarly professional development opportunities were available for educational stopover during rotational moves. Prior to the current downsizing and restructuring era rotational moves also provided enough movement in the personnel system to balance personnel inventory and force structure requirements. Hence, reduced rotational move also has readiness implications. Furthermore, fewer rotational moves will tend to increase CONUS times on station (TOS). This has positive and negative implications. Increased unit cohesion in Table of Organization and Equipment (TOE) units can be a positive effect of longer TOS. On the other hand stagnation can also result from longer

TOS, particularly in TDA support units where soldiers do not keep up their war fighting skills.

Two permanent change of station policies are examined to address the issues raised above. The first policy is to maintain the status quo. Under it an increase in CONUS TOS and a decline in number of rotational moves is expected. The second policy is reducing Germany's tour length from three years, the current length, to two years. This policy should produce more rotational moves and fewer operational moves. An analysis using TAPLIM will provide information on the implications and consequences of these options.

Method of Analysis

The analysis involves employing TAPLIM for each policy option. The first policy, the status quo, requires no modification of model parameters. For the alternative policy, some parameter modifications are required to accommodate the two-year Germany tour length. In TAPLIM, changing Germany tour length to two years is equivalent to requiring that 50 percent of the enlisted personnel stationed in Germany in a period move to another location in the next period. The GAMS version of the PCS extension of TAPLIM has a location movement rate table. The rates in this table designate the proportion of soldiers who can move from one location or unit to another. The table is indexed by grade, location exited, and the location entered. Reducing the tour length for Germany to two years requires changing the rates for remaining in Germany to .50.

The results from the TAPLIM runs for the alternative policy option and the current policy were then imported into a spreadsheet. Comparisons of undermanning, the number of rotational and operational moves, and implied CONUS time-on-station are made.

Findings

Tables 1, 2 and 3 present a brief summary of the TAPLIM results for the two policy scenarios examined. Table 1 provides the number of rotational and operational moves by fiscal year for each policy. Implied time-on-station[4] (TOS) for CONUS TOE and CONUS TDA units estimated from TAPLIM's analysis results are presented in Table 2. Table 3 presents, for both policies, yearly underdeviations for Korea and Germany, two locations where manning levels are critical.

Some of the repercussions from the personnel system of the current downsizing and restructuring of the Army is unknown. TAPLIM's analysis of the current policy may provide some insight into the consequences of ongoing changes to the force structure. Table 1, for example, indicates that both rotational and operational moves, moves from one CONUS location to another CONUS location, will decline under the current

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4 Implied time-on-station is calculated as the reciprocal of the total number of soldiers moving out of a location during a period divided by the total number of soldiers in the location at the beginning of the period.

policy, with rotational and operational moves falling between FY93 and FY97 by 35 percent and 200 percent, respectively. The reduction in rotational moves may adversely affect promotions, professional development, and readiness. Furthermore, the decline in operational moves may cause stagnation. (Note that operational moves are under estimated in TAPLIM since intra-TOE and intra-TDA moves are not considered.) Further insight into the current policy is provided in Table 2. The results show TOS increasing for CONUS TDA units but increasing only through FY95 and thereafter declining for CONUS TOE units. If these TOS trends suggested by the model persist they could have negative effects on the force. Results from Table 3 indicate that undermanning levels in 1997 may be as large as 1700 and 1325 for Germany and Korea, respectively. These levels may be too large and the current policy could have deleterious impacts on the force.

Table 1
Number of Movements by Fiscal Year

FY93	Current Policy	GERMANY = 2 Yrs.
Rotational	69,874	70,062
Operational	30,668	25,718
Total	100,542	95,780
FY94		
Rotational	61,325	61,921
Operational	20,217	15,455
Total	81,542	77,376
FY95		
Rotational	54,588	65,984
Operational	10,911	12,257
Total	65,499	78,242
FY96		
Rotational	48,838	56,668
Operational	13,662	6,390
Total	62,500	63,058
FY97		
Rotational	45,464	52,533
Operational	9,762	11,093
Total	55,226	63,626

The column header "Policy Scenarios" spans over "Current Policy" and "GERMANY = 2 Yrs."

The alternative policy of decreasing the Germany tour length from three to two years is now examined. Table 1 shows, as expected, that the alternative policy produces more rotational moves and fewer operational moves in most instances than the current policy. Fewer operational moves mean longer time-on-station in CONUS. Table 2 reveals that for the alternative policy CONUS TDA time on station increases less rapidly, while TOE time-on-station increases more rapidly than the current policy. Thus TDA units would experience less stagnation and TOE units would experience greater cohesion. Table 3 indicates that over the 5 year projection period the alternative policy produces a better

match between the inventory and requirements for Germany but a worse match for Korea.

Table 2
Impled Time on Station (Years)

	Current Policy		Germany = 2 Yrs.	
Fiscal Yr	TDA	TOE	TDA	TOE
FY93	2.6	2.9	2.7	3.1
FY94	2.7	2.6	2.7	4.7
FY95	3.3	4.5	2.7	4.2
FY96	3.6	3.9	3.0	4.8
FY97	3.7	3.2	3.7	2.5
Average:	3.2	3.4	3.0	3.9

Table 3
Underdeviation by Geographic Area

	Current Policy		Germany = 2 Yrs	
Fiscal Yr	GER	KOR	GER	KOR
FY93	7,168	2,938	4,718	2,498
FY94	0	0	823	2,384
FY95	600	525	614	579
FY96	612	258	761	0
FY97	1,730	1,325	1,003	833
Total	10,110	5,046	7,919	6,294

Summary

This paper describes the conversion of the TAPLIM linear program to a GAMS formulation, with the intention of establishing TAPLIM as a user-friendly policy analysis tool. TAPLIM's level of detail allows an analyst to observe effects of policy changes by time period, grade, and years of service, and geographic location. The GAMS formulation of TAPLIM is also easier to modify and quicker to solve than the original LINDO formulation. These attributes make TAPLIM a more effective tool for determining the long term feasibility of proposed policy changes. TAPLIM's capabilities are illustrated with an example that involves analyzing current and alternative PCS policy scenarios. TAPLIM is now running at the U.S. Army Reseach Institute (ARI) on the VAX computer system. There are plans to move it onto a Pentium platform.

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